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The Los Alamos Neutron Science Center Spallation Neutron Sources

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Abstract

The Los Alamos Neutron Science Center (LANSCE) provides the scientific community with intense sources of neutrons, which can be used to perform experiments supporting civilian and national security research. These measurements include nuclear physics experiments for the defense program, basic science, and the radiation effect programs. This paper focuses on the radiation effects program, which involves mostly accelerated testing of semiconductor parts.

When cosmic rays strike the earth's atmosphere, they cause nuclear reactions with elements in the air and produce a wide range of energetic particles. Because neutrons are uncharged, they can reach aircraft altitudes and sea level. These neutrons are thought to be the most important threat to semiconductor devices and integrated circuits. The best way to determine the failure rate due to these neutrons is to measure the failure rate in a neutron source that has the same spectrum as those produced by cosmic rays.

Los Alamos has a high-energy and a low-energy neutron source for semiconductor testing. Both are driven by the 800-MeV proton beam from the LANSCE accelerator. The high-energy neutron source at the Weapons Neutron Research (WNR) facility uses a bare target that is designed to produce fast neutrons with energies from 100 keV to almost 800 MeV. The measured neutron energy distribution from WNR is very similar to that of the cosmic-ray-induced neutrons in the atmosphere. However, the flux provided at the WNR facility is typically 5×10^7 times more intense than the flux of the cosmic-ray-induced neutrons. This intense neutron flux allows testing at greatly accelerated rates. An irradiation test of less than an hour is equivalent to many years of neutron exposure due to cosmic-ray neutrons.

The low-energy neutron source is located at the Lujan Neutron Scattering Center. It is based on a moderated source that provides useful neutrons from subthermal energies to ~100 keV. The characteristics of these sources, and ongoing industry program are described in this paper.

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Keywords: Spallation; neutrons; semiconductor devices; user facility; LANSCE.

1. Introduction

The Los Alamos Neutron Science Center (LANSCE) uses a high-current medium-energy proton linear accelerator, to accelerate both positive and negative hydrogen ions that can be delivered to multiple experimental areas simultaneously (Fig. 1). The drift tube linac accelerates the proton beam to 100 MeV while the side-coupled cavity linear accelerator accelerates the beam up to 800 MeV with pulsed beam timing patterns suitable for a wide variety of experimental programs (Lisowski and Schoenberg, 2006). Presently, the H^+ beam is accelerated to 100 MeV and is used to produce medical isotopes for diagnostic and therapeutic applications. The H^- beam is accelerated to 800 MeV and is transported to the Weapons Neutron Research (WNR) and the Lujan Center. LANSCE has a high-energy and a low-energy neutron source for semiconductor testing. The high-energy neutron source at the WNR facility uses a

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bare target that is designed to produce fast neutrons with energies from 100 keV to almost 800 MeV. The low-energy neutron source is located at the Lujan Neutron Scattering Center. To provide a suitable time structure for low-energy neutron time-of-flight experiments, a Proton Storage Ring (PSR) compresses 625 μs pulses from the linear accelerator to 125 ns (FWHM) at a rate of 20-30 Hz (Lisowski and Schoenberg, 2006). The protons then impinge on a tungsten target producing spallation neutrons that are further slow-downed through the target moderator-reflector-shield (TMRS) to provide neutron energies from subthermal to ~100 keV.

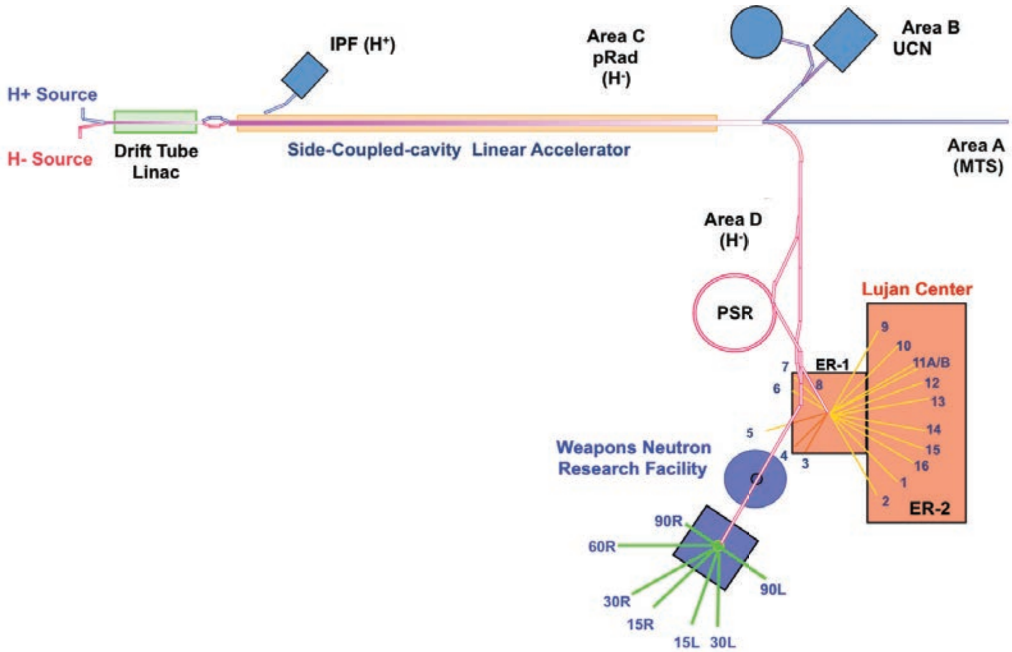

Fig. 1. layout of LANSCE facility

2. High-Energy Neutron Source: WNR Facility

The high-energy neutron source at WNR uses the 800 MeV pulsed proton beam with an average current of approximately 4 μA. High-energy neutrons are produced at the WNR facility through the spallation of the protons on a tungsten target (Lisowski and Schoenberg, 2006). The neutron production target consists of a tungsten cylinder, which is 7.5 cm long and 3 cm in diameter. The target is enclosed in a 4 mm thick water jacket for cooling. There are currently six flight paths (FPs), as seen in Fig. 2, where the neutrons produced have energies between ~1 MeV to over 600 MeV. The shape of the neutron energy spectrum depends on the angle of the FP relative to the incident proton beam. The neutron output, Y, from the target in neutrons/proton/MeV/sr for various FPs is shown in Fig. 2 where the angle of the FP is relative to the incident proton beam. As seen in Fig. 2, the more forward FPs have greater high-energy neutrons than the larger angle FPs.

2.1. The Irradiation of Chips & Electronics (ICE) Facility

The radiation field in space originates from galactic cosmic rays and solar particle events. When cosmic rays interact with the elements in the atmosphere, secondary particles are produced. Our atmosphere not only creates secondary particles but also absorbs the particles. In general, at the surface of the earth, most of the charged particles have been absorbed and only the neutrons, because they are uncharged, remain. These neutrons can interact with the materials in the semiconductor and produce charged particles, which can deposit charge in sensitive volumes of the semiconductor. This deposited charge can cause failures of electronic devices.

The best way to determine the failure rate of semiconductor devices due to the neutrons induced by cosmic rays is to measure the failure rate in a neutron source that has the same spectrum as those produced by cosmic rays. The measured neutron energy distribution from WNR FP 30L and 30R (see Fig. 1) at LANSCE is very similar to that of the cosmic-ray-induced neutrons in the atmosphere. However, the flux provided at the WNR facility is typically 5×10^7 times more intense than the flux of the cosmic-ray-induced neutrons. This intense neutron flux allows testing at greatly accelerated rates. An irradiation test of less than an hour is equivalent to many years of neutron exposure due to cosmic-ray neutrons.

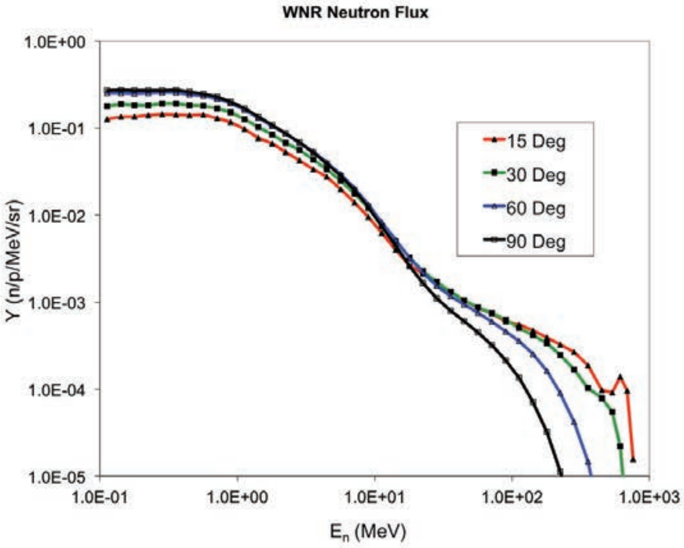

Fig. 2. WNR neutron intensity spectrum as a function of the angle respective to the proton beam.

The ICE facility was constructed to perform accelerated neutron testing of semiconductor devices. Flight Path 30L and 30R, called ICE House and ICE-II, allow users to efficiently set up and conduct measurements. Because the FP of ICE-II is shorter than that of ICE House, the neutron intensity in ICE-II is greater. Figure 3 shows the neutron spectrum produced at LANSCE WNR for the ICE House and ICE-II compared with the cosmic-ray neutron spectrum measured by Goldhagen (1997). In Fig. 3, the WNR flux is divided by 5×10^7. The integrated neutron flux above 1.5 MeV in the LANSCE beam is approximately 1.5×10^6 n/cm^2/s for ICE House and 4.7×10^6 n/cm^2/s for ICE-II. The beam spot size diameters can be adjusted between 2.5 and 8 cm for ICE House and 2.5 and 6.4 cm for ICE-II. Figure 4 shows the beam upstream and downstream of a semiconductor device placed in the beam. As seen in Fig.4, the uniformity is excellent.

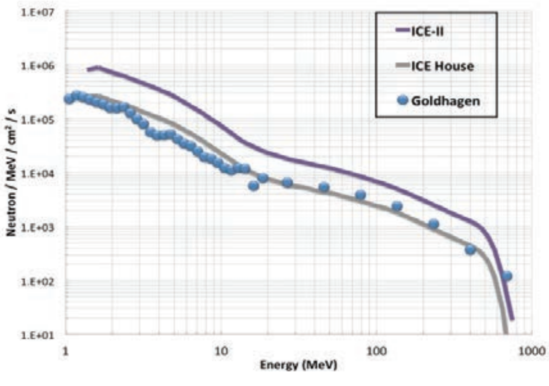

Fig. 3. FP30L and 30R neutron intensity spectrum vs. cosmic-ray induced neutrons (Goldhagen, 1997).

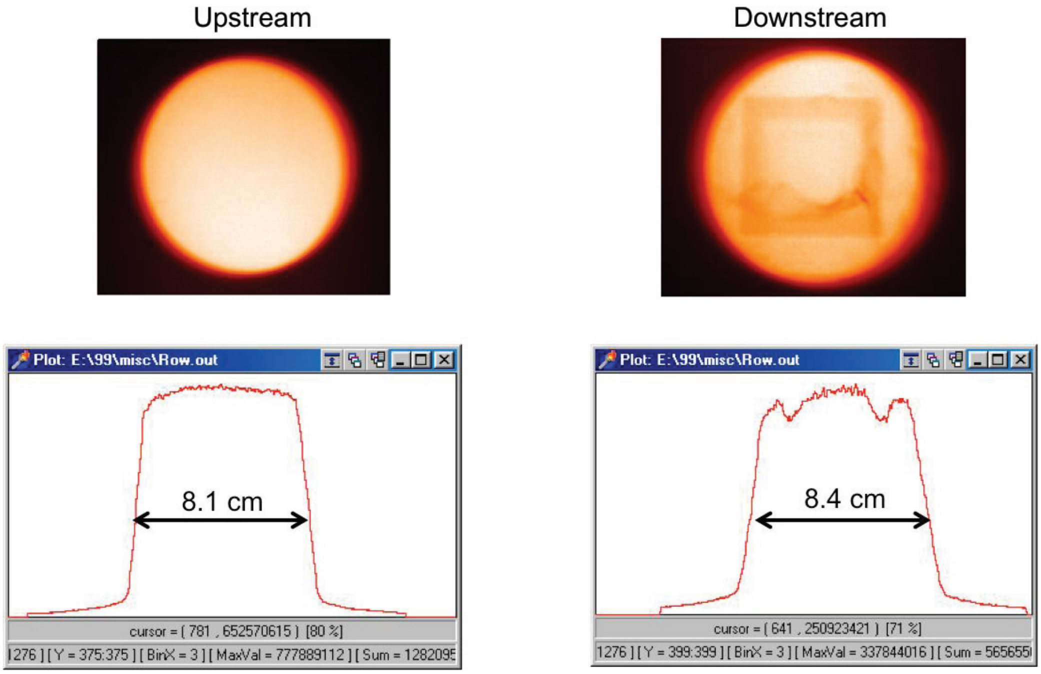

Fig. 4. The beam spot in the ICE House. The diameter of the beam is approximately 8 cm. The downstream beam spot shows the shadow of a semiconductor part inside the beam spot.

The floor plan of the ICE House experimental area is shown in Fig.5. The area is divided into two parts: the beam area and the data room area. The beam area is where the semiconductor devices can be placed in the neutron beam and the data area is where experimenters can monitor and control their experiments. The two areas are separated by shielding. When the beam is on, the beam area cannot be occupied.

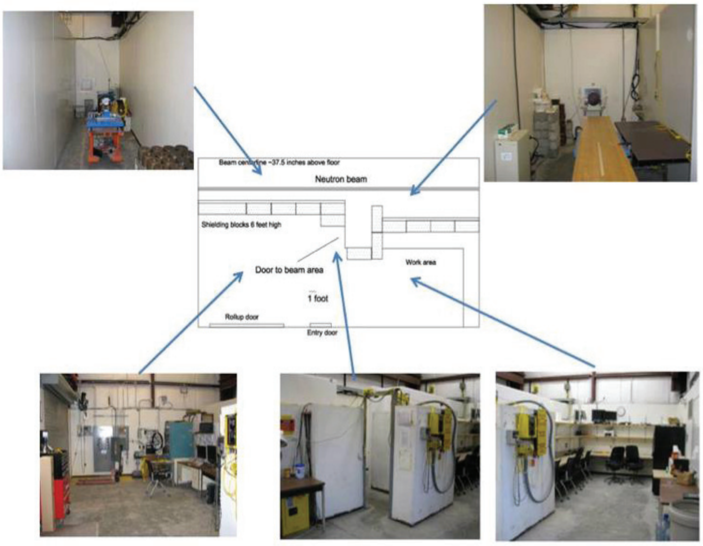

Fig. 5. the floor plan of the ICE house experimental area.

3. Low-Energy Neutron Source: Lujan Neutron Scattering Center

3.1. Target design

Lujan Center's neutron production was optimized to deliver cold and thermal neutrons to neutron-scattering experiments. The current Mark-III Target-Moderator-Reflector-Shield (TMRS) consists of a split target design and moderators and reflectors as seen in the elevation plot in Fig. 6 (left). The split target consists of two W pieces to produce neutrons that are then scattered to 16 FPs. The FPs are distributed over two tiers as follows: the lower tier consists of three chilled H_2O and one LH_2 + chilled Be moderators to deliver cold and thermal neutrons to 12 FPs. The upper tier consists of one LH_2 and one chilled H_2O moderators to deliver cold and thermal neutrons to 4 FPs. A cross section view of the lower and upper tier can be seen in Fig. 6 (right). Recently, there have been efforts by Nowicki and Mocko (2015) to study the feasibility to provide a higher intensity in the epithermal and medium energy ranges while preserving most of the thermal and cold neutron capabilities that currently support neutron scattering experiments. This new design will enable many new nuclear physics experiments that are currently limited by neutron intensity or energy resolution available at existing neutron FPs at LANSCE.

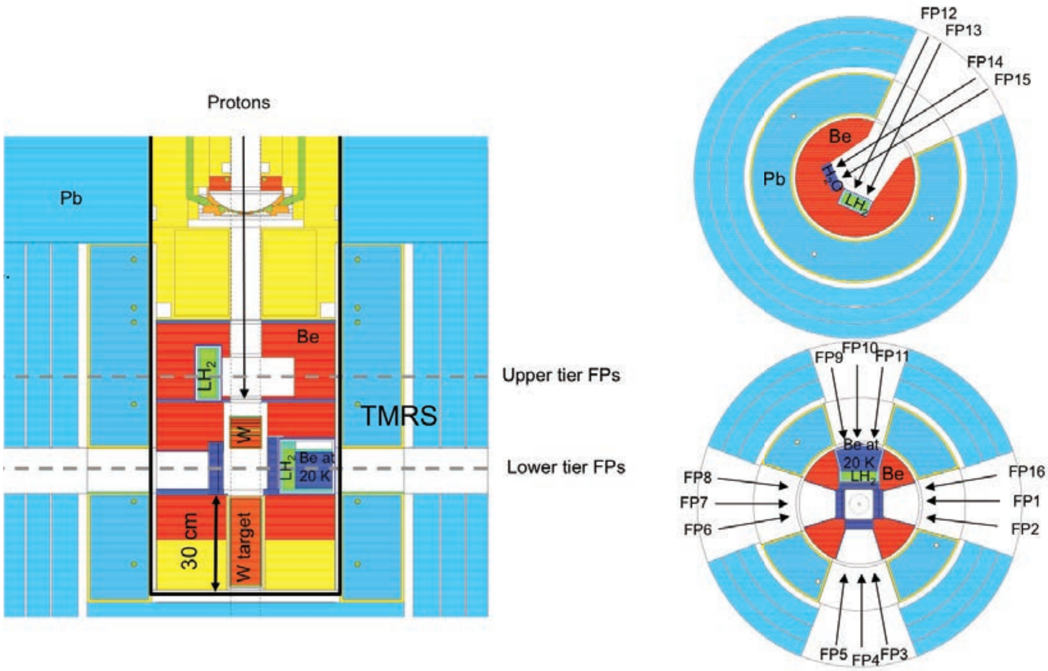

Fig. 6. (left) Elevation plot of Mark III TMRS; (right) Cross section plot of the upper (top) and lower (bottom) tiers.

3.2. Thermal Neutron Flight Path

Recently, the avionics community has become concerned about the effects of thermal neutrons on integrated circuits. Thermal neutrons can be produced from high-energy neutrons thermalizing in the aircraft fuel, passengers and aircraft materials. These thermal neutrons can be captured by ^{10}B that is in the integrated circuit parts and produce an energetic alpha particle, which can deposit enough charge to cause a single event effect.

The effects of thermal neutrons on semiconductor devices can be measured using the low-energy neutron source at the LANSCE Lujan Center. It is possible to perform measurements with cadmium shielding in and out of the beam to reduce the high-energy components in the flux and backgrounds. The neutron flux is approximately 2×10^7 neutrons/cm^2/s between 1 meV and 0.4 eV as shown in Fig. 7.

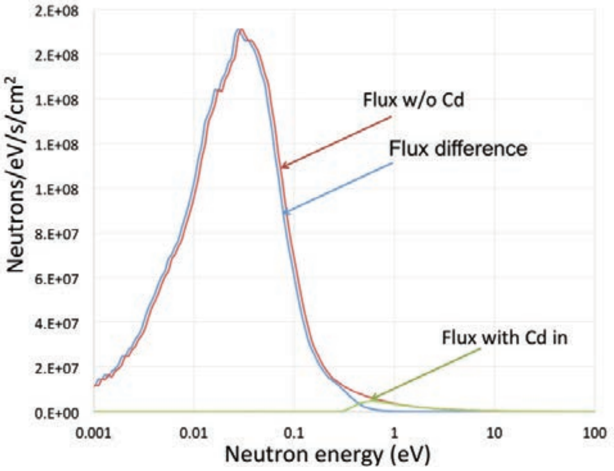

Fig. 7. Thermal neutron measurement is possible at LANSCE Lujan Center through cadmium shielding to reduce the high-energy components.

3.3. Summary

The best way to determine the failure rate of semiconductor devices due to the neutrons induced by GCRs is to measure the failure rate in a neutron source that has the same spectrum as those produced by cosmic rays. The measured neutron energy distribution from WNR at LANSCE is very similar to that of the cosmic-ray-induced neutrons in the atmosphere. However, the flux provided at the WNR facility is 5×10^7 times more important than the flux of the cosmic-ray-induced neutrons. This intense neutron flux allows testing at greatly accelerated rates. An irradiation test of less than an hour is equivalent to many years of neutron exposure due to cosmic-ray neutrons.

The effects of thermal neutrons on semiconductor devices can be measured using the low-energy neutron source at the LANSCE Lujan Center. It is possible to perform measurements with cadmium shielding in and out of the beam to reduce the high-energy components in the flux and backgrounds. The neutron flux is approximately 2×10^7 neutrons/cm^2/s between 1 meV and 0.4 eV. As the current TMRS of the Lujan Neutron Scattering Center approaches the end of its life, we are working on a new design that will enable new nuclear physics experiments that are currently limited by neutron intensity or energy resolution available at existing neutron FPs. Using Monte Carlo N-Particle eXtended (MCNPX), we have worked on several conceptual designs where 4 neutron FPs will provide a higher intensity in the 0.001 – 1 MeV energy range while the other 12 FPs will preserve most of the thermal and cold neutron capabilities that currently support neutron scattering experiments (Nowicki et al, in preparation).

Contact information and procedure to use the LANSCE facilities can be found at the Los Alamos Neutron Science Center website: http://lansce.lanl.gov/users/index.php.

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